HST study of the Stellar Populations within 30 pc of SN 1987A

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Abstract
We have studied the stellar populations in a region of 30 pc around SN 1987A in the Large Magellanic Cloud using multi-band *HST*-WFPC2 images. The effective temperature, luminosity and reddening of each detected star were determined by fitting the measured broad band magnitudes to the ones calculated with model atmospheres. The resulting HR diagram reveals the presence of stars with ages between 1 and 150 Myrs, superposed on a much older field population. The youngest stars in the field appear to be T Tauri stars, characterized by strong Hα excesses. The Star Formation Rate has increased monotonically in the last 8 Gyrs and the star formation activity is still very high at present. *Young* stars of low and high mass have different spatial distributions. The latter ones are strongly concentrated in the vicinities of the Supernova, whereas the previous ones are more evenly distributed on the field. Hence, the Mass Function varies on a scale of a few parsecs. However, averaging over the entire area, one can define an Initial Mass Function, well fitted by a power-law with a slope $\alpha \lesssim -2.55$. The uncertainty on the IMF due to incompleteness in identifying T Tauri stars is discussed.

1 Introduction

SN 1987A is located at the SW edge of the Tarantula Nebula, some 20′ away from its center. The whole area contains a large number of early type stars interspersed with HII regions and SNR shells. The OB association closest to SN 1987A is LH 90, which is located about 5′ to the NE of the supernova (Lucke & Hodge 1970) and whose age is much younger than that of SN 1987A progenitor, *i.e.*, about 4 Myrs as compared with the 10-11 Myrs as estimated for Sk -69 202 (*e.g.* Van Dyk, Hamuy and Mateo, 1998). It is clear that the study of SN 1987A neighborhood offers a unique opportunity to place the supernova explosion in the proper context of stellar evolution and the evolution of stellar populations.

2 Observations and Data Reduction

SN 1987A has been observed with various instruments on board HST since 1990. In particular, as part of the SINS project (**S**upernova **IN**tensive **S**tudy, PI Kirshner), we have now a series of multifilter images that give an excellent coverage over an area of about 130″ radius, *i.e.* about 30 pc, centered on SN 1987A. Here we present the results of the analysis of the SINS images taken with the WFPC2 camera, using the F255W, F336W, F439W, F502N, F555W, F656N, F675W, F814W filters (in the following we shall refer to the broad bands as UV, U, B, V, R and I although they do not coincide with any of the canonical ground based color systems). We also use an archival F656N image taken in early 1994 under project #5203 (PI Trauger).

After processing the observations through the PODPS (Post Observation Data Processing System) pipeline for bias removal and flat fielding, we have removed cosmic ray hits by combining the two available images in each filter. Finally, we performed aperture photometry following the prescriptions of Gilmozzi (1990) with the refinements as described by Romaniello (1998). The flux calibration was obtained using the internal calibration of the WFPC2, which is typically accurate to better than ± 5%. In this way we obtained the photometry of a total of 21,955 stars. More than 15,000 of them have a photometric accuracy better than 0.1 *mag* in the V, R and I filters. This number drops to 6,825 in the B band and only 786 stars have a UV filter uncertainty smaller than 0.2 *mag*.

3 The HR Diagram

The large number of bands available (6 broad band filters) which cover a wide baseline (more than a factor of 3 in wavelength, extending from 2550Å to 8140Å) provide us with a sort of *wide-band spectroscopy* which defines the continuous spectral emission distribution of each star quite well. Therefore, by comparison with model atmospheres (Bessel et al, 1998), one can fit the 6 band observations of each stars and solve for 3 unknowns simultaneously, namely the effective temperature, T_{eff}, the reddening, $E(B-V)$, and the angular radius, R/D. In practice, this can be done only for stars with effective temperatures higher than about 10,000 K and between 8,500 and 6,500 K (for details, see Romaniello, 1998). Therefore, we first solved for the full set of parameters, T_{eff}, $E(B-V)$, and R/D only for stars suitably selected on the basis of reddening-free colors. For each of the remaining stars, we adopt the average reddening of its first neighbors and solve for only two parameters, T_{eff}, and R/D. Finally the stellar luminosity is computed from the derived T_{eff} and R/D, adopting a distance to SN 1987A of 51.4 *kpc* (Panagia 1998). The resulting $\log\left(L/L_{\odot}\right)$ vs. $\log\left(T_{eff}\right)$ plot (HR diagram) is shown in Figure 1.

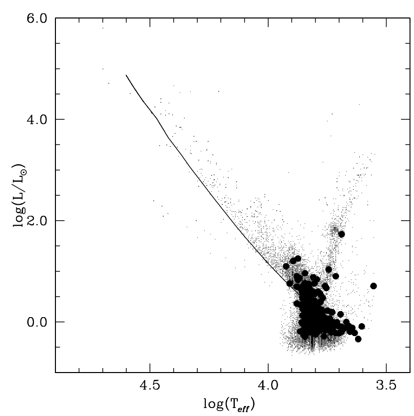

Figure 1: HR diagram for the 21,955 stars in the field around SN 1987A. T Tauri stars identified through their Hα excess are shown as dots. The full line shows the location of the ZAMS for $Z = Z_{\odot}/3$ from the models of Brocato and Castellani (1993) and Cassisi et al (1994).

By comparing the R band magnitudes with the ones measured in the Hα narrow band filter we identified the stars with strong Hα excess ($R - m(H\alpha) > 0.25$, i.e. $W_{eq}(H\alpha) > 8$Å). We identify the luminous and bright ones (5 stars), which are near the MS, as Be stars whereas we believe that the redder and fainter ones (488 stars) are T Tauri stars, i.e. Pre-MS stars with circumstellar material, remnant of their proto-stellar cocoons. The vast majority of these stars also show a U-band excess, *i.e.* very blue U−B colour given their B−I one. Again, this is interpreted as due to the accretion of material from the disk. With this criterion, we identify 850 T Tauri candidates.

An inspection of the HR diagram confirms the early findings of Walker & Suntzeff (1990) and Walborn et al (1993) and reveals that:

- The distribution of stars in the HR diagram is clearly bound toward high temperatures, identifying a ZAMS that corresponds to a metallicity $Z \simeq Z_{\odot}/3$.
- The positions of the most luminous blue stars fall on isochrones corresponding to ages around 10-12 Myrs, which make them coeval to SN 1987A progenitor and Star 2 (Scuderi et al 1996).
- There are a number of stars at intermediate luminosities and temperatures (say, $\log(L/L_{\odot} \sim 2-4$ and $\log(T_{eff} \sim 3.8-4.2)$ that indicate distinct stellar generations, with ages in the range 40-150 Myrs.
- The lower MS and the red giants are mostly old populations, consistent with a metallicity either identical to, or slightly lower than the one of the young components.

No single age can explain the distribution of the old population, and stellar generations between 600 Myrs and 6 Gyrs are required to account for the observations.

- Among the stars with substantial Hα excess we identify 488 strong T Tauri stars, whose positions in the HR diagram indicate ages from 1-2 Myrs up to 10-20 Myrs, according the Pre-MS isochrones of Siess et al (1997).

4 The spatial distribution

As shown in Figure 2, the spatial distribution of early type, massive stars and the one of PMS stars does not correlate well with each other. The ratio of low mass to high mass stars belonging to the most recent episode of star formation shows big variations across the field. For example, it is of the order of unity in the central area, where Supernova 1987A is, while elsewhere it varies between roughly 7 (south-east of SN 1987A) and 28 (south-west of SN 1987).

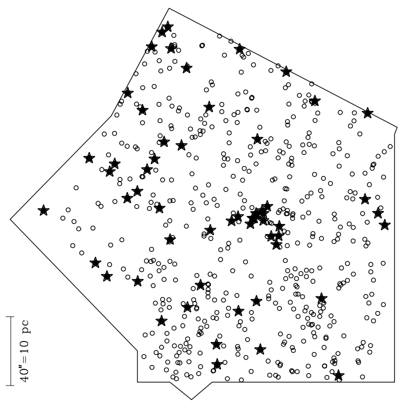

Figure 2: Spatial distribution of massive (star symbol) and Pre-Main Sequence (circles) stars.

In general, there is a lack of massive stars in the south-west corner, where the T Tauri stars are most most numerous.These differences are highly significant because they greatly exceed the simple Poissonian fluctuations. An experimental check of this fact is provided by similar statistics on the number of stars belonging to the Red Giant clump. They are part of a much older population which, therefore, should be uniformly distributed over the field. Indeed, the observed number densities for these stars show fluctuations perfectly in agreement with Poisson statistics.

The almost anti-correlation of spatial distributions of high and low mass stars of a coeval generation indicates that star formation processes for different ranges of stellar masses are rather different and/or require different initial conditions. An important corollary of this result is that the very concept of an Initial Mass Function seems not to have validity in detail, but may rather be the result of a random process, so that it could make sense to talk about an average IMF over a suitably large area in which all different star formation processes are concurrently operating.

5 Star Formation History and Initial Mass Function

As we have seen, the observations cannot be explained in terms of a single generation of stars. We have recovered the Star Formation History of the field by assigning an age (and mass) to every observed star by comparing its position on the HR diagram to the evolutionary models by Brocato and Castellani (1993) and Cassisi, Castellani and Straniero (1994). The result is shown in Figure 3

An inspection of Figure 3 shows that the Star Formation Rate has been increasing in the past 5 Gyr by a factor of 15 if the value of the bin centered at 4.5 Gyr is taken as representative of the star formation activity in the remote past. However, this bin too may be affected by incompleteness problems. In a more conservative way, we can take the SFR value at 3.5 Gyr as representative, in which case the enhancement is a factor of 6.

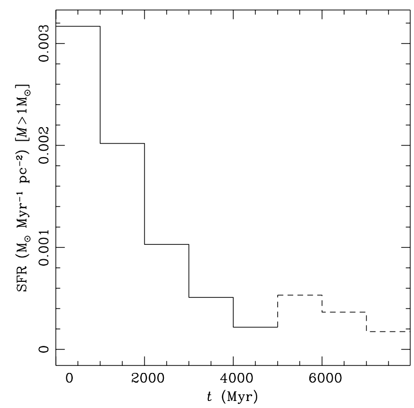

Figure 3: SFR for the field around SN1987A. Look back times greater than 5 Gyr are affected by incompleteness (dashed histogram).

The derived IMF is shown in Figure 4. Let us stress here that this is a *spatial and temporal average* resulting from the superposition of different generation of stars and needs not to be valid for any of them individually.

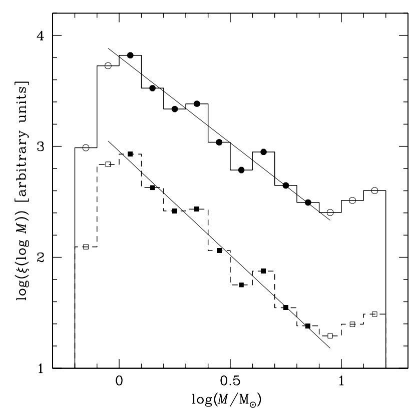

Figure 4: IMF including only stars with Hα excess (full line) or also those with U-band excess (dashed line).

A least-square fit in the $1 \leq M/M_\odot \leq 7$ interval, where the sample is not affected by incompleteness, yields a slope of $\alpha = -2.55$ if only the stars with Hα excesses are included in the young population and a value of $\alpha = -2.87$ if also the stars with U-band excesses are added.

Full account of this work can be found in Romaniello (1998).

6 References

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